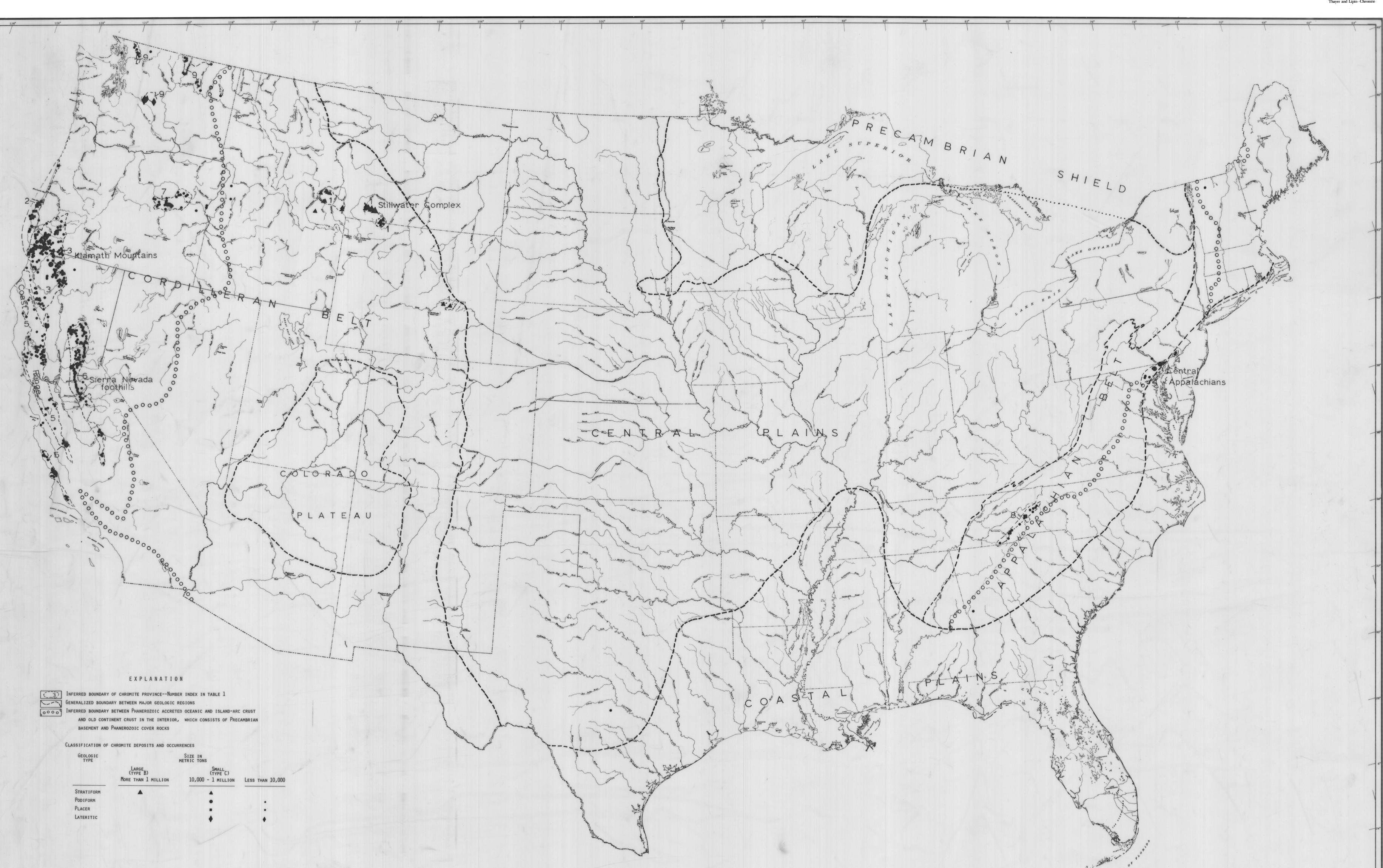
Thayer and Lipin--Chromite

79-576R



Planimetric Base from National Atlas 1:7 500 000, 1970

This map of the conterminous United States is divided into areas called provinces that contain chromite deposits. Chromite is the source of chromium, a metal that is indispensable to our industrial society, but whose resources are limited in the conterminous United States (Thayer, 1973). The sizes and geologic types of deposits, the geologic host rocks, and preliminary estimates of the resources are indicated for each province. No chromite mines are currently producing in the

As an alloy in steel, chromium improves strength, hardenability, and resistance to corrosion and oxidation. More chromium, by far, goes into making stainless steel (containing 18 percent chromium) than into any other single product. There is no substitute for the chromium in stainless steel, although in other types of alloys nickel, cobalt, niobium, molybdenum, or vanadium may be used to some extent, but at greater expense (Morning, 1977). Chromium is used in the chemical industry principally for plating, pigments, and tanning; chromite ore is used as a high-temperature refractory lining in In 1976, the United States consumed the equivalent of about 1.5 million tons (1.65 million short tons) of chromite, 60 percent in ferroalloys (metallurgical), 20 percent in refractories, and 20 percent for chemicals (Morning, 1977). According to U.S. Bureau of Mines, the demand will grow at an

annual rate of 3.8 percent to 2000 A.D., the equivalent of about 3.3 million tons of ore per year. Because its chromium resources are subeconomic, the United States normally imports this metal from Eastern Hemisphere sources. By improving secondary recovery and through rigorous substitution, consumption might be cut by two-thirds in 10 years, but at substantial economic cost (Natl. Materials GEOLOGIC AND ECONOMIC FEATURES OF CHROMIUM DEPOSITS

The mineral chromite, which consists of oxides of chromium, iron, magnesium, and aluminum, is the only economic source of chromium. The proportions of the four main oxide constituents vary widely, and the chemical composition of the ore determines its principal uses and price as follows: Price/metric ton (in 1976 dollars) Types of ore High-Cr High-Al High-Fe Metallurgical

Chemical and Metallurgical 40- 45

Natural ores are mixtures of chromite and other minerals that are waste or gangue, and therefore vary greatly in grade. Low-grade natural ores have to be concentrated to higher grades for use. To compare resources in this report, the chromite contained in crude ore has been calculated to a standard usable (shipping) grade. The two main sources of chromite are primary or lode deposits, and secondary deposits formed by weathering and erosion. Lode deposits contain the predominant minable resources of the world and occur almost exlusively in a very distinctive rock called peridotite. The largest lode deposits, of the stratiform type, form layers that range in thickness from a few centimeters to 3 or 4 m, and in

extent from a few to tens of kilometers. A few chromite layers in southern Africa contain billions of tons of high-grade ore and constitute more than 95 percent of the world's minable chromite resources. Lode deposits of the podiform type, however, occur as irregular lenses or pods that are disbributed more or less randomly in essentially massive peridotite. Most podiform deposits range in size from a few kilograms to a few thousand tons; a very few contain as much as 1 million tons each. Stratiform deposits may be mined systematically because of their regularity, but the irregularity of pods makes mining more difficult and expensive. The search for concealed podiform deposits is very unpredictable, mostly because of their random distribution and limited size; despite a great deal of research, no economically feasible methods have been devised to find them in most districts. Under especially favorable conditions in a very few districts, however, geophysical methods have been

instrumental in locating some relatively large ore bodies. Secondary chromite deposits also are of two kinds: (1) laterites, soils that have formed by weathering of the peridotite host rock, and have not been moved far from their original location; and (2) black sand heavy-mineral concentrations. In tropical climates chromium, along with iron, nickel, and cobalt, is concentrated in laterite by solution and removal of the other rock-forming elements. Most laterities contain only about 0.5 to 1.5 percent Cr₂O₃, but they cover hundreds of square kilometers in some tropical and subtropical regions, and constitute a major potential source of chromium. Chromite resists weathering and, because it is heavy, accumulates as black sand when fine soil is eroded away. Stream sands were once mined for chromite on a small scale in Maryland and North Carolina. Along the Pacific Coast, chromite eroded from peridotite in the Klamath Mountains in

California and Oregon has been concentrated to minable grade by wave action on modern and ancient Since 1820, the United States has produced about 1.9 million tons of chromite of which nearly half came from stratiform deposits in the Stillwater complex in Montana (table 1). Podiform deposits California and Oregon have yielded about 670,000 tons, about one-third of the national total; Pennsylvania and Maryland produced the remaining one-sixth. At present rates of consumption, total domestic chromite production is equivalent to about a 15-month supply.

CHARACTERISTICS OF CHROMITE PROVINCES

The chromite province map and table l define those regions or geologic terranes in the conterminous United States where chromite is known to occur and form previously economic deposits. Province boundaries have been drawn to enclose mining districts, clusters of small deposits or occurrences, and favorable geologic environments. The relative sizes of the four main geologic types of deposits are indicated on the map. A large mine or deposit is defined (Tooker, 1980) as one that contains more than 1 million tons (1.1 million short tons) of chromite. The only province known to contain such deposits is the Stillwater province where the grade is such that the chromite was worth \$40 to \$45 per ton in 1976. Because no chromite has been mined in the United States since 1976, all mines and deposits shown on the map are inactive and fall in types B and C according to size (Tooker, 1980). Two former mines on the Stillwater complex in Montana, the Mouat and Benbow, are shown on the map as large type B deposits, each of which contains more than 1 million tons. All the other map symbols represent known small (type C) deposits and occurrences, none having combined production and estimated resources equivalent to more than 250,000 tons of shipping-grade ore.

The resource data are from Miller and Thayer (1962), Vhay (1966), Thayer and Hobbs (1968), and U.S. Geological Survey files. Some of the technical terms used here and in the atlas of metals and nonmetals, of which this map is part, are discussed and defined in a companion background report by Tooker (1980). Some of the geologic data used are from the geologic map of the United States (King At least 200 chromite mines and prospects are town in the Blue Mountains province in eastern Oregon. More than 90 percent of the total production (30,000 tons) has come from an area of about 80 km² of peridotite in the Canyon Mountain complex near John Day, and all mines that have produced more than 1,000 tons each are in this complex. The deposits are of the podiform type, and most production has been of high-chromium ore. The largest deposits, however, are of milling-grade, high-aluminum chromite for which there has been little demand. Identified resources of 150,000 tons are mostly of high-aluminum ore in two deposits, the larger of which has not been completely drilled. The estimate of 200,000 tons of undiscovered resources is based on geologic projection to a depth of about 75 $\mathrm{m} \cdot$ The chromite deposits outside the Canyon Mountain complex are small lenses that are widely scattered in isolated masses of peridotite.

southern part of the province are believed to be small. The possibilities for mining chromite

CHROMITE PROVINCES

Rocks known to contain chromite of economic interest occur in three main regions of the United States; in order of combined production and estimated resources they are: the Stillwater province in southwestern Montana; the Pacific Coast region in California, Oregon, and Washington; and the Appalachian region that extends from Georgia to Vermont (table 1). Stillwater province (1)

The Stillwater province in southwestern Montana consists of two mountain ranges, each about 100 km long, in which chromite deposits are exposed. The Stillwater complex and Red Lodge districts are in the eastern or Beartooth Mountain block. Only four small, low-grade deposits, one of which produced 1,000-2,000 tons of high-iron chromite concentrates, are known in the western block. The chromite deposits in the province are stratiform and high in iron. Chromite layers that occur in a belt about $1.5\,$ km wide and $50\,$ km long in the lower part of the Stillwater complex constitute at least 80 percent of the identified chromium resources of the United States. Several nearly vertical layers can be traced more than 25 km and extend downward to unknown depths where they are not cut off by major faults (Jackson, 1963, p. 58). The two thickest layers, out of 13 that are known, have yielded about 909,000 tons of concentrates averaging 38.9 percent Cr₂O₃. In the Red Lodge district, 40 km southeast of the Stillwater complex, lenses of chromite- bearing rocks are scattered over an area of about 120 km 2 . The chromite ore bodies range in size from a few kilograms to nearly 15,000 tons, and the district yielded 34,200 tons of ore that averaged 34.5 percent $\mathrm{Cr}_2\mathrm{O}_3$. Chromite from the Stillwater province cannot compete commercially with South African ore, because it is

significantly lower in grade (32-40 percent Cr_2O_3 versus 44-46 percent) and much more expensive to The chromite resources of the province are estimated as equivalent to about 7.5 million tons of shipping-grade concentrates. Of this total, 2.5 million tons are considered identified resources in layers of the Stillwater complex that have been mined previously and probably extend down at least to the level of the Stillwater River. Undiscovered resources possibly amounting to 5 million tons may be found ultimately at greater depths, and subeconomic resources are known in thin layers of the complex. Identified resources in Montana other than in the Stillwater complex are estimated at about 50,000 metric tons of very high Fe concentrates.

The main hope for finding more chromite in the Stillwater province is in buried extensions of the Stillwater complex. The geological similarities of all the deposits in Montana to the Stillwater complex indicate that they may be remnants of once larger masses. The nature of the smaller deposits, including those in the Red Lodge district, however, indicates that the hypothetical original complex or complexes have been fragmented, and most of the chromite deposits may have been destroyed by deepseated processes, or eroded away. Despite detailed mapping, mining, and other underground work in the Stillwater complex, determination of the ultimate resources will require much more geophysical work and deep drilling. Geologic mapping of the western mountain block is in progress to evaluate the probability of finding major extensions of the Stillwater complex.

The chromite deposits south and east of Casper, Wyo., are similar to those near Red Lodge and are regarded as isolated outliers of the Stillwater province. The smaller of the two deposits produced about 1,900 tons of ore before 1920 and was mined out. The deposit south of Casper is so low in grade, and the chromite so rich in iron, that, although theoretically it might yield 50,000 tons or more of concentrates, mining is unlikely even at extraordinary prices for chromium. The Klamath Mountains, Coast Ranges, and Sierra Nevada provinces of California and Oregon (3, 5, 6) The Klamath Mountains-Coast Ranges and Sierra Nevada form two north-south-trending belts. The

western belt (Klamath Mountains-Coast Range) extends about 905 km along the West Coast from southwestern Oregon almost to Santa Barbara, Calif. The eastern belt extends about 550 km along the Sierra Nevada foothills. The chromite deposits of the three provinces are all podiform and widely scattered in peridotite. Nearly 600,000 tons of chromite have been shipped from the three provinces, and about 150,000 tons of chromite remain in identified deposits. Although more than 450 mines are known, about 75 percent of the production came from 20 mines, and the other 430 mines accounted for only 25 percent. The U.S. Geological Survey estimates that there are about 700,000 tons of undiscovered resources in the three provinces, about 50 percent in the Klamath Mountain province, and 25 percent each in the

Oregon-California beach sand province (2) Chromite-bearing black sands occur in present beaches and in adjacent raised beach deposits over a distance of about 200 km along the coast of southwestern Oregon and northwestern California. The chromite in the sands was eroded from peridotite in the Klamath Mountain province and concentrated by wave action (Griggs, 1945). The sands were mined on a small scale for gold before 1900. During World War II several terraces or raised beaches were explored systematically for chromite, and by 1955 about 52,000 tons of concentrates had been shipped. The concentrates are very similar in grade to those from the Stillwater complex, being high in iron and ranging between 37 and 40 percent ${
m Cr}_2{
m O}$ Separation of chromite from other heavy minerals, especially ilmenite, requires special processing and the sand can be mined in open pits. Chromite remaining in drilled deposits is estimated at 500.000 tons and unexplored terrace deposits probably contain a similar amount. Resources in the

Blue Mountains province (7)

PRELIMINARY MAP OF CHROMITE PROVINCES IN THE CONTERMINOUS UNITED STATES

Scale 1:5,000,000

Thomas P. Thayer and Bruce R. Lipin

Table 1.--Chromite provinces of the United tates in order of production through 1976 and estimated resources, in thousands of metric tons of shipping ore Status of

Province			Production	Resource potential		Status of geologic knowledge	
No.	State	Area		Identified	Undiscovered	Adequate	Insufficien
1	Montana-Wyoming	Stillwater complex	965	2,500	5,000(H) ¹		Х
2	Oregon- California	Beach sands	50	500	500(L) ²	,	X
3	California- Oregon	Klamath Mountains	285	80	400(L)		Х
4	Pennsylvania- Maryland	Central Appalachians	250-300		300(L)	X	
5	California	Coast Ranges	190	20	200(L)		X
6	California	Sierra Nevada foothills	115	75	200(L)		X
7	Oregon	Blue Mountains	30	150	200(L)	Χ	
8	North Carolina	Southern Appalachians	.42	< 5	<5(L)	X	
9	Washington	Northern Washington	<.3	10	40(L)		X

Central Appalachian province (4) Chromite deposits are known over a distance of about 1,850 km along the Appalachian region from

northern Vermont to western Georgia, but the main areas of concentration are in the State Line

Baltimore about 1811, but records before 1900 are very incomplete. The total production of the

peridotite about 50 km long by 0.9-2.4 km wide. Three mines, the Wood, Reed, and Red Pit, yielded 90

percent of the lode ore, and probably more than 15,000 tons was obtained from stream placers in Maryland (Pearre and Heyl, 1960). All known large deposits have been mined out, and identified resources are a few hundred tons at most. Undiscovered deposits comparable in size to the Wood ore

body (100,000-200,000 tons) probably occur in the district within mining distance of the surface.

Postulated resources to the depth of the Wood mine workings, about 150 m, may therefore be as much as

Southern Appalachian province (8)

420 tons of ore during World War I. Lenticular bodies of peridotite are scattered along the province as outlined, but most contain no known chromite deposits. Identified chromite resources are a few

hundred or a few thousand tons at most, and the outcrops of rocks that might contain chromite are too small to encourage exploration for concealed ore bodies. Stream sands and deep soils on peridotite might yield a few hundred or thousand tons of placer chromite at very high prices.

North-central Washington (9)

Chromite occurs in primary podiform and secondary laterite-type deposits in the north-central Washington province. Production from podiform deposits has been small. Old buried laterite deposits near Cle Elum probably consist of several million tons of material containing 0.5 to 1.0 percent

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Small chromite deposits in the southern Appalachian province, in western North Carolina, produced

The State Line district is the heart of the province; it consists essentially of a belt of

district of Pennsylvania and Maryland, and in western North Carolina. Chromite mining began near

province is estimated to be between 250,000 and 300,000 tons.

Geological Survey Bulletin 945-E, p. 113-150.

of Sciences, Publication NMAB-335, 347 p.

Geological Survey Professional Paper 580, p. 372-374.

250,000-300,000 tons.

chromium (Vhay, 1966).

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

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